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THE SUN,

AND THE

PHENOMENA OF ITS ATMOSPHERE.

By Prof. C. A. YOUNG, Ph.D.,
OF DARTMOUTH COLLEGE.

NEW HAVEN, CONN.:
CHARLES C. CHATFIELD & CO.
1872.

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THE SUN

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Charles Augustus
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OF DARTMOUTH COLLEGE.

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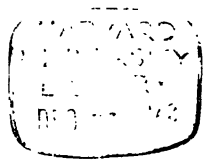

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PREFACE.

The following pages contain the substance of a lecture delivered at New Haven last January before the Yale Scientific Club. In its preparation for the press however considerable alteration and addition has been necessary, as the original delivery was mainly extemporaneous, and interspersed with numerous experimental illustrations, which cannot be reproduced in the printed form.

It is of course impossible to include within such limits anything like a complete statement of our present knowledge concerning the sun: for this, one must have recourse to such works as Proctor's "Sun" or Secchi's "Le Soleil." The new German edition of the latter book, revised and edited by Dr. Schellen, is especially to be commended as a most complete and admirable exhibition of the present state of Solar Science, and it is greatly to be hoped that it may soon appear in an English dress.

The aim of this lecture is more humble—simply to present a general view of the subject, which, without descending into details, shall be accurate as far as it goes, and shall observe so far as possible the due proportion of parts; and to put this in such form and language as shall be easily understood by that large portion of our educated and intelligent public, who, without being exactly scientific themselves, are yet deeply interested in the results and methods of scientific research.

Great pains have been taken to secure accuracy in every statement of fact or opinion, and although it is not impossible that errors may have crept in, it is hoped they will be found unimportant.

As regards the relative importance of topics discussed or omitted, it has sometimes been difficult to decide, and it is very likely that scientific readers, should any such honor this little pamphlet with their perusal, will consider that some points have been too much enlarged upon at the expense of others equally important. Still I have faithfully tried to avoid this fault, and to give a fair and well proportioned representation of the subject.

DARTMOUTH COLLEGE, *March*, 1872.

THE SUN AND THE PHENOMENA OF ITS ATMOSPHERE.

BY PROF. C. A. YOUNG, PH.D.

Ladies and Gentlemen:

I am sure that in this place and before this audience no elaborate introduction is needed to excite an interest in the subject upon which I am to speak to you this evening.

Certainly to us, dwellers upon the earth, the Sun is preëminent among physical objects, not only on account of the wonders of his own nature, but still more because of the important relations in which he stands to all terrestrial activity.

Swedenborg in his system of so-called "Correspondences" has made this body the type and representative of the Deity; and this most rightly, even in a fuller sense than he himself seems to have been aware; for the Sun is no mere symbol of the Deity, but so to speak, His material vicegerent, through which alone He dispenses to us vitality and power, and all physical benefits, in the forms of Light and Heat and those still subtler influences whose nature and operation are as yet but darkly understood.

The winds, the rivers, the waves of the ocean and its

profoundest currents, are driven and maintained by the Sun. All the power of steam is his, derived at second hand from treasures of solar energy garnered up in fuel.

By the inscrutable processes of vegetable and animal vitality his power is stored away in various organic products, by the consumption of which alone our human life and activity are maintained; so that on close analysis we recognize the transformation of solar force not only in our mechanical actions, the motions of our limbs and the sound of our voices, but even in the higher functions of thought and passion. As long as our immaterial souls are confined in bodies, and work only by means of brain, nerve and muscle, so long it is true that for all energy of thought, all intensity of feeling, all vigor of action of whatever kind, we are ultimately dependent upon the Sun.

Let this not be misunderstood however—I do not deny or ignore the distinction, essential in the very nature of things it seems to me, between mind and matter, body and spirit.

The engineer with his hand upon the valve-gear of the locomotive, controls, but in no sense supplies, the power that drags behind him the thundering train.

No more does the soul within us raise the hand or move the tongue or rack the brain. Its office is higher,—by an utterly mysterious connection with the springs of life it superintends and controls the expenditure of energy through that most perfect and wonderful of all machines, the human body. But the energy thus put at the soul's disposal is from the Sun, mainly at least, for the remotest stars contribute each their quota.

Since then all terrestrial activity is thus "Sun-derived" it is only reasonable to feel profound interest in every-

thing relating to this body: in fact for the last few years an unusual amout of observation and research has been concentrated upon the subject, and, as is always the case with any faithful study of nature, many very interesting and important discoveries have already rewarded the labor.

I propose accordingly to occupy the hour with a brief statement of the principal facts at present known about the Sun, giving special prominence to those results and methods of investigation which are of most recent date, and this as far as possible in language simple and untechnical.

And here, perhaps, is the proper place to say that in preparing for this lecture I have been greatly impressed with the scantiness of our real knowledge. Some facts, indeed, can be stated with confident certainty, but to a very great extent our ideas regarding the solar constitution and modes of action are based upon mere hypotheses of greater or less plausibility, and I am free to confess that my own studies for the past few years have done quite as much to unsettle for me old beliefs as to establish new ones. While not a few difficulties have vanished in the light of freshly-discovered facts, a still more numerous crop has come up in their place.

DISTANCE OF THE SUN.

The first thing to be ascertained if possible with reference to a heavenly body is its distance. A knowledge of this is essential to any determination of its real magnitude and weight, and these must be known before we can form a correct idea of its physical constitution and modes of action.

Did time permit, it would be interesting to explain

some of the many methods by which the distance is determined, and especially to recall the course by which was discovered and corrected an error of more than three per cent. in the value universally accepted less than twenty years ago. At that time the distance was considered to be about 95 millions of miles—it is really less than 92. This is the average distance, but the sun is some three millions of miles nearer on the first of January than on the first of June.

While there is very little doubt however that the sun's mean distance is between 91 and 92 millions of miles, the margin of error is still pretty large,—probably half a million of miles one way or the other,—and it is in hopes of adding greatly to the precision of our knowledge that astronomers are now looking forward with so much interest to the coming transits of Venus in the years 1874 and 1882.

These phenomena, usually occurring about twice in each century, furnish the most accurate means of ascertaining the solar parallax, upon which the calculation of this distance depends, and the different governments are already taking measures to provide for the necessary observations. I am sure you will all join me in the wish that our own country may not be behind the rest.

I do not suppose that in stating the distance of the sun as 92 millions of miles I have communicated to you any real notion. Probably I might just as well have said 92 billions. The conception is too vast to be fairly grasped by the human intellect, but perhaps one or two illustrations may assist in the matter.

If on some intermundane railway between the earth and the celestial metropolis the Pilgrim Fathers had started from the sun at the same time when they really

left England, and if they had travelled by special express at the rate of 40 miles an hour, without stops, (since there could be no way stations on such a line,) they would not yet have arrived, nor would their train be due until 1883 —363 years upon the road. At the present time, with only 11 years more to go, they would still be 16 times as distant as the moon: so remote that the earth would be to them only a brilliant planet, of about one-fifth the moon's diameter.

A cannon ball, moving straight on unretarded with its swiftest speed, could not make the journey to the sun in 9 years.

If sounds could travel through the celestial spaces at the same rate as in our air, then the thunder of a solar storm or the report of an explosion such as occurred last September, might reach us in a little more than 14 years.

And yet across this tremendous chasm the sun exercises his lordship and performs his service; every pulsation of the solar surface is instantly responded to upon the earth.

The distance of the sun once determined it is very easy to ascertain his diameter, which comes out 860,000 miles, nearly 109 times as great as that of the earth.

Representing the earth by a boy's ball 2 inches in diameter, the sun on the same scale would be something more than 18 feet through. If the earth were placed at the centre of the sun the moon would be far within his surface, so far indeed that there would be room within it for another moon almost as far again from the earth.

In bulk it would take more than a million and a quarter earths to make a globe of equal size.

Knowing the distances of the sun and moon, the

lengths of the year and of the month, it is easy by methods which I cannot now stop to explain, to ascertain what is called the *mass* of the sun, that is to say the number of tons of material in it; or, since the ton would be a ridiculously small unit for such a measurement, the number of *earth-weights* in it.

The sun weighs very nearly 325,000 times as much as the earth.

Recalling the fact that it is 1,250,000 times as bulky-it is of course evident that bulk for bulk it is much lighter than the earth, or, to speak technically, its *density* is only about ¼ that of the earth—about 1¼ times that of water.

This is a most important and suggestive fact when taken in connection with this other fact, that on the sun the force which attracts bodies to his surface, the solar gravity, is about 28 times as great as terrestrial gravity.

On the earth a body let fall drops about 16 ft. in the first second; on the sun it would fall 450 ft. The stately swing of the pendulum of an astronomical clock would at the sun become a quiver more rapid than the vibration of the quickest watch balance.

A graceful lady, whose sylphlike form here would hardly weigh 100 pounds, if carried to the sun would become as unwieldy as an elephant, or rather would be crushed by her own weight. Her airy little head alone would weigh nearly 250 pounds.

Now it would at first seem that the remarkable lightness of the solar substance and the great power of solar gravity can be reconciled only by supposing the sun to be in the main a gaseous mass, a mere cloud of vapors: towards this conclusion also many other facts converge, such as the intensity of the solar temperature and

the peculiar motions observable upon his surface. At present this may perhaps be regarded as the prevailing opinion among men of science—only an hypothesis however, not yet by any means fully established. It seems to have been first seriously proposed and defended by Secchi, and afterwards adopted and more cogently enforced upon different grounds by the French astronomer Faye, who is commonly credited with its paternity.

Some eminent astronomers however dissent from this view. Zöllner for instance still holds that the central core of the sun is liquid, or at least, if mainly gaseous, is covered with a liquid shell in a condition analogous to ebullition—*i. e.*, throwing off continually vast bubbles of gas that form the so-called prominences; of which more anon.

Many simply withhold assent, on the ground that where the conflicting influences of pressure and temperature so far transcend all terrestrial experience it is unsafe to dogmatise. From what we can learn upon the earth it would seem that no substance could possibly remain a gas under such pressures as those that must prevail even a few hundred miles below the solar surface, though perhaps the recent researches of Andrews partly remove the difficulty. It seems equally certain that all substances must be vaporized when exposed to such intensity of heat.

For one I am willing to own that we have no very certain knowledge as to the condition of the sun's central mass; nor for that matter do we know much about the earth's.

TEMPERATURE OF THE SUN.

I say the sun's temperature is exceedingly intense. This is evident from many circumstances.

From very elementary principles of the science of

heat it follows that the temperature of a body placed in the focus of a lens or mirror will not rise above that of the source of heat whose rays are there concentrated, and must generally fall very far short of it; in fact the action of the lens is simply to effect a virtual transportation of anything placed in its focus towards the source of heat. Now in the focus of a burning lens 3 feet in diameter the most refractory solids—platinum, fire clay, the diamond itself—are either instantly melted or dissipated in vapor, and this although, taking into account the imperfections of the lens, the heat in its focus is no more intense than if the body were simply placed at a distance from the solar surface considerably greater than the moon's distance from the earth. There can be no doubt that if the sun should approach as near us as the moon, the earth itself would melt.

Other proofs of the intensity of the solar temperature could easily be given did time permit.

Many attempts have been made to measure it; but while the experiments in themselves are sufficiently simple and accordant, very little reliance can probably be placed in the numerical results. These are deduced from the experiments only by means of hypotheses as to the laws of radiant heat, which are very precarious and by no means generally conceded. There is certainly an enormous discordance between the conclusions of different investigators. Thus Secchi contends for a temperature of 18 millions of degrees (Fahrenheit), Ericsson claims 4 or 5 millions, Zöllner, Spoerer and Lane, temperatures ranging from 50,000 to 100,000 degrees, while Pouillet, St. Claire Deville, and perhaps the majority of physicists put the probable figures between 3,000° and 20,000°. The intensest artificial heat reaches perhaps 4,000°.

But although the *temperature* of the sun is thus uncertain it is not so with the quantity of heat emitted, which is quite a different matter. This can be, and has been, determined with considerable accuracy by various methods, all based however upon the same principle—the measurement of the elevation of temperature produced in a given quantity of water by the action of a sunbeam of known diameter in a measured time. It would take too long to enter into the details of the experiment, and to explain all the precautions and corrections required; but there is nothing in the whole process beyond the comprehension of any one.

By experiments of this kind at the Cape of Good Hope in 1838 Sir John Herschel ascertained that the heat received by the surface of the earth from the sun in the zenith, would be sufficient to melt a layer of ice one inch thick in about 2 hours, 12 minutes.

Now as there is no reason to suppose that more heat falls upon the earth than upon any other surface of equal size at the same distance, it follows that if the sun were surrounded by a complete shell of ice having the same diameter as the earth's orbit and one inch thick it would all be melted in the same time, *i. e.* 2h. 12m.; furthermore, if we suppose this shell to contract, growing thicker of course so as to maintain the quantity of ice unchanged, it would still, since it intercepts as before all the heat thrown off from the sun, be melted at the same rate—just so many tons of ice per hour: and if we imagine it to shrink clear down upon the very surface of the sun we find that the solar fire would melt its way out at the rate of nearly 40 feet a minute. The same result substantially has been arrived at by several other observers.

To produce this effect by the burning of anthracite coal would require a layer 13 ft. thick all over the sun to be consumed every hour—⅔ of a ton per hour to every square foot of surface—such a fire as no earthly furnace can ever parallel. At this rate if the sun were made of solid coal he would burn entirely out in less than 6,000 years.

Herschel employs the following illustration:—If a rod of ice 45 miles in diameter could be darted at the sun with the velocity of light, while by some means the whole radiation of the solar heat could be concentrated upon its advancing extremity, it would never reach the sun at all; it would be melted as fast as it approached. Or we may put this into another form. Let us suppose that we build an ice bridge to the sun for that intermundane railway of which I was speaking a few minutes ago. Make its base upon the earth two miles square, and carry it up solid and of the same size throughout, past the moon, and by the orbits of Venus and Mercury across the whole abyss of more than 90 millions of miles, and recall that for the swiftest railway train to traverse this bridge, without making a single stop, would require a period of more than 360 years; and now upon this massive beam of polar ice suppose the sun to concentrate all his rays; the pendulum swings but *once;* in *one second* it is melted, and before the ninth beat of the clock it has completely vanished, dissipated in vapor. Such is the solar fire.

According to Joule's estimate of the so-called mechanical equivalent of heat, which is certainly correct within one per cent., the amount of heat which would raise one degree (Fahrenheit) the temperature of one pound of water, if transformed into work by a perfect

heat-engine, could be made to lift a weight of 772 pounds to the height of one foot.

Assuming this, we find that every year each square foot of surface at the earth's equator receives from the sun sufficient heat to raise 53 tons to the height of a mile. This heat is principally used in maintaining the earth's temperature, replacing what the earth radiates into space. Perhaps about $\frac{1}{1000}$ of the whole is annually stored up by animals and vegetables, or consumed in work: but even this minute fraction is an abundant revenue of power for the whole human race.

And now come such questions as these; what maintains this tremendous furnace, what is its fuel; for how many ages has it blazed as now, and when if ever will come the day of its extinction?

I cannot answer any of them, nor can any one I think, with certainty in the present state of science.

A comparison between the climates of the present day and those of two thousand years ago, based principally upon data derived from the geographical limits of the growth of plants, especially the vine and cereals, shows conclusively that during this period the heat annually received from the sun has not materially altered.

Geological facts show that for untold ages before our own era there have been alternations of greater heat and severer cold than we are familiar with; at one time a carboniferous epoch when the earth was covered with a tropical vegetation, and then an age of ice.

So far then as can be ascertained from facts of observation it is impossible to assert that the sun is growing either warmer or colder.

At first sight it seems to follow from this apparent

constancy of the solar heat that, for the present at least, the sun must be receiving as much as it throws off, and the sources of such a supply have been earnestly inquired for; thus far without avail.

No chemical combinations or combustions such as terrestrial chemistry makes us familiar with could account for it, so enormous is the amount. If the sun were solid coal he would be consumed in less than 6,000 years, as I have said before.

The theory proposed a few years ago by Mayer that the solar heat is due to the incessant fall of meteoric matter has also been conclusively refuted, since it has been proved that any supply sufficient to account for such a radiation must disturb the motions of the planet Mercury to an extent which is irreconcilable with observation. Some small fraction of the solar heat indeed may really be traceable to this cause, but as things stand it looks as if the sun were throwing off into space a far greater amount of matter than it receives.

Still less satisfactory is the theory of Williams,* who finds the "fuel of the sun" in a hypothetical universal atmosphere through which the sun and his attendant planets move.

It has been suggested that the constancy of the solar

* One remark upon which Mr. Williams insists seems to deserve a moment's notice—this namely, that any theory of the solar heat is worthless, that does not equally explain that of the stars (so far good), and that "does not also account for the perpetual renewal, the constancy, the eternal permanence of all these radiations."

This latter doctrine is, to say the least, questionable. If the study of nature teaches anything, it is that nothing material is permanent in its condition. Everywhere we see the marks of progress and development—of movement at least, from a beginning towards an end.

temperature for the past two thousand years is only apparent: that in fact the temperature has been falling all the time, only at too slow a rate to be detected by any rough comparisons of ancient and modern climates.

It is impossible, however, to account for such an enormous radiation in this way unless we assume for the material of the sun a "specific heat" as it is called far exceeding that of any known substance.

But it does not follow that a body which is losing heat faster than it receives it, is necessarily growing cooler, that is, falling in temperature. The statement may seem paradoxical, but it is true.

Suppose for instance a vessel of water at a temperature of 40° is brought into a room where the air is below zero. At first the water grows colder and colder, as a thermometer immersed in it would show, until it sinks to the freezing point. What then? The mercury remains stationary at 32°, although the water is still losing heat all the time; but the water freezes, and not until every drop of the water is turned into ice, a process which requires considerable time, 142 times as long as was occupied by the water in cooling from 33° to 32°, does the thermometer resume its downward march.

Thus it is quite possible that the sun may be continually losing heat without receiving any supply of importance from without, and yet maintain its temperature unchanged for ages while it contracts, liquefies, solidifies, or undergoes some other change in the molecular constitution of its materials.

This I think is the view most generally received at present, though the precise nature of the molecular changes which disengage such a heat is by no means

certain: indeed it is altogether probable that many different actions conspire in the one grand effect; the liquefaction of vapors, the solidification of liquids, a general contraction and diminution of bulk, and especially the combination of gases before dissociated.

But take what view we will, it is evident that such an evolution cannot of itself go on forever; there is continual progress toward an end, and only some interposition of creative power can avert the otherwise inevitable termination—the final extinction of the sun.

SURFACE OF THE SUN.

When examined with the telescope the sun appears as a round disc considerably brighter at the centre than at the edge and with a peculiarly mottled surface, much like that of curdled milk. Under high magnifying powers this surface is seen to be made up of little granules, much like rice kernels in form as a usual thing, but in some cases drawn out into longer filaments like willow leaves.

Near the edges of the disc there are generally bright streaks and patches of irregular form called *faculæ*, but the most noticeable objects are dark spots of curious appearance and of a great variety of shapes.

In regard to the nature of the solar surface three different views are current, only one of which however, is generally received.

According to the first, which is held by Zöllner and I suppose by Kirchoff and some others, the luminous surface is *liquid*, the pores and granulations being partly caused by spots and streaks upon the fluid itself, and partly by clouds of varying constitution in an overlying atmosphere.

A second hypothesis mentioned by Secchi as possible,—which indeed would seem to be the only one consistent with his enormous estimate of the solar temperature, though he does not quite venture to adopt it—is that the luminous surface is a sheet of rolling *flame*, if I may use that term; not of course a flame of chemical action, but simply intensely heated gas under pressure, shining like the electric arc or the flash of lightning.

The remaining theory, which is the one most probable and almost universally accepted, lies intermediate between the others, and recognizes in the photosphere, as it is called, neither a gaseous nor a liquid surface, but a stratum of luminous clouds. It is supposed that when the vapors of the different substances contained in the solar atmosphere are exposed to the cold of outer space, partial condensation takes place, and clouds are formed just as they are in our own atmosphere; but while our clouds are made up of minute drops of water, these solar clouds must be composed of drops of melted metal—of incandescent iron, magnesium, sodium, &c., far more intensely luminous than the gases from which they are condensed, driven and carried by the solar winds, and continually changing their form and appearance.

It is difficult to ascertain with much accuracy, the thickness of this luminous shell, but from some peculiarities in the motions and appearances of the spots it is usually estimated at from 3,000 to 8,000 miles.

The faculæ are undoubtedly elevations upon the photosphere,—ridges and waves of luminous matter rising considerably above the general level, and so to speak pricking through the overlying atmosphere which

dims the light of the rest. When by the rotation of the sun they are carried around the edge, a little tooth is sometimes seen to project, showing an altitude of several hundred miles; for it must be remembered that at the distance of the sun an object 450 miles in diameter subtends only an angle of one second, and requires a magnifying power of at least 100 to make it even barely visible.

SPOTS.

But the spots are by far the most interesting objects. The illustration (Fig. 1), taken from Secchi's work upon the sun—to which by the way I am greatly indebted for many of the materials of this lecture,—gives a very good idea of their ordinary appearance.

You notice of course the black central portion, which is called the *umbra*, of irregular form but roughly circular. Then around this you have the dark *penumbra*. You observe that there is no gradual shading from the umbra into the penumbra, nor of the latter into the photosphere; in fact the penumbra is really darkest at its outer edge. You see also how all the filaments and dark streaks of the penumbra are directed towards the centre of the spot; frequently indeed the appearance of the penumbra is so very like that of a shelving clay bank gullied by the rain, that the streaks are sometimes called rills, as if they were caused by streams running towards the central aperture.

Then you will notice also the little grains of luminous matter which float over the umbra. The diameter of this particular spot—the umbra—was about 10,000 miles, so that the earth could be dropped through the hole,—if hole it really is,—without touching the sides at all. But the spots vary greatly in magnitude: they

very rarely attain a diameter of more than 50 or 60 thousand miles, though they sometimes exceed even that limit, becoming so large as to be easily visible by the naked eye when the sun is obscured by fog, or is near the horizon. Some also are exceedingly small, mere black dots 4 or 5 hundred miles in diameter, and such are called pores.

But while the figure is an excellent representation of a well behaved and well formed spot in its quiet middle life, it does not give any idea of the wild youth and dissolving age of such an object, or of the strange disturbances that frequently torment its career.

When the spot is forming, and when it is about to disappear, the whole neighbourhood is thrown into violent commotion; the penumbral filaments are drawn into spiral whirls; bright streaks called bridges shoot across the dark nucleus, often at the rate of more than a thousand miles an hour; and the area of the spot enlarges or contracts with a similar velocity, while its form is continually changing in the most unexpected and fantastic manner.

There are instances on record in which a spot of 50,000 miles diameter has formed in a single day, and others where their disappearance has been as sudden. Perhaps the average life time of a solar spot is about 3 months, but one group observed in 1840–41, the Methuselah of its race so far, endured for 18 months.

They are not generally stationary upon the solar disc, but drift forward, though not by any means with a steady motion: according to Secchi, and I think I have observed the same thing, each new paroxysm of disturbance is accompanied by a sort of forward jump, which causes the spot to leave behind it a trail of pores and

faculæ. I say forwards, meaning by this that the motion is in the direction of the sun's rotation; for the sun like the earth rotates upon its axis from East to West, but much more slowly.

And now as to the nature of the spots: what are they? One thing is settled beyond question—they are *cavities* in the photosphere; but whether they are orifices reaching clear through this stratum and revealing some less luminous core below, as the Herschels have held; or whether the central umbra is formed by a mass of comparatively dark and opaque vapors collected in a simple hollow; or whether, as Zöllner holds, the umbra is a floating slag upon the liquid shell which he believes to underlie the photosphere, is as yet doubtful.

That the nucleus is depressed below the general surface of the photosphere is made evident by the fact, discovered now just one hundred years ago by Wilson, that when the spot first comes into view at the edge of the solar disc, and again when it leaves it, the penumbra is always wider on the side of the umbra which is next the edge; in some cases also when a large spot is just passing out of sight a distinct indentation is perceived.

It is reasonably certain too that directly above the umbra of the spot there is a strong vertical current in the solar atmosphere, and this produces a powerful indraught towards the centre of the spot along the surface of the photosphere and in that cloud stratum itself. This explains the appearance of the penumbra, which is due to the breaking up of the photosphere around the centre of disturbance by this inward suction; the cloud flakes torn off by its action move rapidly towards the nucleus where they disappear, and the penumbra at its inner edge is brighter than at the outer simply

because in thus drawing inwards the filaments are crowded together.

But whether the vertical current at the centre of the spot ascends or descends, and whether the penumbral filaments when they reach the umbra disappear by cooling below the temperature of incandescence, or by being heated to complete evaporation and consequent invisibility, are questions still disputed.

The older view, still maintained by Secchi, is that the spots are formed by an *up-rush* of heated gases from the central mass of the sun, which he believes to be gaseous. Such an upward current breaking through the photosphere from beneath, accounts very well for the appearances seen in the telescope: thus the darkness of the central portion of the spot is explained by the fact that heated gas is far less luminous than incandescent liquid or solid matter like the cloudy photosphere; the appearance of the penumbra also is just what might be expected, and the forward motions of the spots are explained according to this view by the assumption that the central portions of the gaseous mass revolve more swiftly than the external.

But this theory seems to be hardly reconcilable with certain spectroscopic observations soon to be considered, which appear to show that there is no remarkable upward current through the centre of a spot, at least as a usual thing, while all around its margin there are innumerable jets corresponding to the surrounding faculæ.

The contrary doctrine, supported by Carrington, Lockyer and others, teaches that the spots are caused by a *down-rush* of cooler gases from the upper atmos-

phere. They suppose the whole sun, including its upper atmosphere, to rotate with about the same angular velocity, and thus the higher masses of the solar air must of course move faster in miles per hour than the lower, and whenever they descend upon the photosphere, they would press forward relatively and carry the spot in this direction. That such vertical currents must exist, upwards from the heated centre and downwards from the cooling surface, is nearly self evident.

The theory of Zöllner, already alluded to, is quite different. He believes the spot-nucleus to be a scoriaceous mass floating upon the liquid shell of the sun's core like slag upon the molten metal in a furnace. The diminution of the heat immediately above it would of course at once produce a down-rush from the upper air which would account for the penumbra. So far as regards the spectroscopic observations his theory more nearly satisfies them than either of the others; but there seem to be very serious difficulties in regard to the mechanical conditions necessary to the maintenance of such a shell of liquid—in this view, the sun is merely an enormous bubble—and the theory has yet met with no general acceptance.

As has been said before, the spots pass across the sun from East to West in about a fortnight, and from their motion it has been attempted to deduce the period of the sun's rotation. But it is found impossible to obtain a reliable result, because the spots themselves are drifting, and that to some extent systematically: those near the solar equator indicate a rotation-period of a trifle more than 25 days, but as we leave the equator the period becomes longer, until at about lati-

tude 24° it is 26 days, at latitude 35°, 27 days, and at latitude 44°, 28 days. In this calculation the formula of Faye has been used:—the formulæ of Carrington, Spoerer and Zöllner lead to results slightly different, as might be expected, since they are each derived from different series of observations. The probability is that the sun not being solid has no one period of rotation, but different portions of its surface and of its internal mass move at different rates, and to some extent independently of each other, though approximately in one plane about 7° inclined to the ecliptic, and around a common axis. The North pole of this axis is directed towards a point in the constellation Draco not marked by any conspicuous star: astronomers would define its position by saying that its right ascension is about 18h. 44m., and its declination 64°. Some of the more recent discussions of spot observations have led to a suspicion —not as yet confirmed—that the sun's equatorial rotation-period is really variable to the amount of an hour or two.

The idea of course naturally suggests itself that the systematic differences between the velocities of the different portions of the solar surface may be due to currents in the photosphere analogous to the trade winds on the earth.

That regular currents exist in the photosphere is perfectly certain, but they can hardly be identified with our trades; since they show no marked tendency either towards or from the equator. Individual spots indeed often drift pretty rapidly in latitude, and it seems that on the whole spots within 15° or 20° of the solar equator on either side move towards it slightly, while beyond this limit they move away.

Possibly further observations may enable us to distinguish between the effects of currents at different levels, and thus establish some more evident relations between our own terrestrial winds and those upon the sun.

The cause of the circulation must however be widely different. The tropical heat which produces our terrestrial winds comes from the sun itself, and no external action with which we are acquainted could establish such an excess of temperature at the sun's equator. Yet as a matter of fact the researches of Secchi seem to show that this part of the sun's surface is really hotter than the rest. Perhaps this may be partially accounted for by the conjecture of Sir John Herschel, who thought that the centrifugal force of the sun's rotation, by heaping up the atmosphere over the equator might thus diminish the radiation there. But direct observation does not show any perceptible increase of the depth of the solar atmosphere in the equatorial regions, and the cause probably lies deeper still.

Another very important fact relating to the solar spots, and probably closely connected with their peculiar motions, is this, that they are found only on certain portions of the sun: while they are rarely seen upon the sun's equator, they are almost never found in latitudes higher than 40°, and are most abundant in two belts lying between the parallels of 15° and 30°.

But the strangest fact of all is the periodicity of the disturbance of the solar surface, first discovered by Schwabe, and announced by him in 1851. For more than twenty years he watched the sun with true German persistency, noting each day the number and position of the spots, and keeping a careful record. He found the

yearly number of spot groups to range from 25 to 330. Maxima of spot-frequency occurred in 1828, 1837, 1848, 1860 and 1871, with equally well marked minima in 1833, 1844, 1855 and 1867. Thus while the period is about 10 or 11 years, it seems to be somewhat variable, and it is to be noticed that the interval from a maximum to the next minimum is greater than that from minimum to maximum.

The cause of this periodicity is yet to be discovered. The researches of Carrington, De la Rue, Stewart and Loewy during the last few years are indeed by many supposed to show a connection between this phenomenon and the configurations of the planets, and Jupiter and Venus appear to be particularly influential. But it would seem that this result should be received only with caution and reserve for the present. For my own part I should be more disposed to believe with Zöllner that the cause lies in some action of the sun itself,—a kind of geyser-like periodicity in the boiling over of the great cauldron—or rather a short cessation of the boiling, and a partial cooling down.

And yet recalling the remarkable fact that this very periodicity of the solar spots is responded to upon the earth by a corresponding variation of our terrestrial magnetism, it would not be safe at all to assert that planetary influence may not operate upon the sun. The mere lapse of time will of itself decide. If the phenomenon is really caused by the planets there will be no displacement of the periods as the years wear on: if otherwise, the periods and the planets will not long keep step.

THE SOLAR ATMOSPHERE.

It was long ago shown by Sir John Herschel, Arago

and others that the darkening so noticeable at the edge of the sun's disc is most naturally explained by means of a solar atmosphere of no great thickness, but with considerable power of absorption. This idea is confirmed by the fact that at a solar eclipse an arc of rosy light is usually seen to border the edge of the sun just as its last ray is hidden by the moon: so that more than twenty years ago many astronomers of reputation maintained the existence of such an envelope.

But it has been reserved to more recent times and newer instruments to ascertain its nature and extent, and to bring within the reach of daily observation many of those beautiful phenomena which before could only be seen during an eclipse.

Any elaborate or extended account of spectrum analysis would of course be impossible here, but perhaps a few words of explanation may be in place.

You all know how, when a beam of white light passes through a prism, it is separated into its component colors, and also how a lens, like that in a photographer's camera, forms upon a screen an image of any object placed at the proper distance in front of it.

If now the object whose image is to be formed by the lens, be a narrow slit, illuminated by white light, the image itself will be a bright white line upon the screen. But if between the lens and the screen a prism be interposed everything will be altered.

In the first place the direction of the light will be changed as it emerges from the prism, so that we shall have to change the position of the screen; and furthermore since the different component colors of white light are differently refracted, we shall no longer get for the image of the slit the simple white line we had before,

but the beautiful rainbow-tinted ribbon of color which we call the spectrum.

It is really constituted in this way: each kind of light which enters into the composition of white, forms upon the screen its own image of the slit independent of every other kind: the red images fall at one end of the spectrum, then come the orange, yellow, green, &c., until we find the violet at the other extremity. And since the countless tints, which go to make up white, shade gradually into each other without any abruptness, the succession of colored images is unbroken also, and they lap upon each other from one end of the screen to the other without gaps or sharp transitions,—we get what we call in technical language a *continuous spectrum.*

But if the light with which the slit is illuminated be not white, then we shall get effects varying according to circumstances. If certain rays be wanting, the corresponding images of the slit will be absent, and dark bands or stripes will appear in the spectrum; if certain rays abound, the corresponding portion of the spectrum will be abnormally brilliant, and a bright line will be seen.

Now it is found that if the light is derived from either a solid, a liquid, or a compressed gas, the spectrum will be continuous, unless the light is altered in composition after it leaves the luminous body. If the material be but slightly heated, its light is usually mainly red—it is *red*-hot—but as the temperature rises the other colors of the spectrum appear in their order, until at last it is thoroughly incandescent, *i.e. white*-hot, and the spectrum is complete, unmarked by lines or bands of any kind.

If on the other hand the light is derived from an in-

tensely heated gas or vapor, not too much compressed, the effect is very different and exceedingly beautiful.

The spectrum now is made up of bright lines and bands; each substance giving its own peculiar system differing from every other as much as any written name differs from other names; so that to a practised observer the spectrum of a substance in this condition is a name as clearly legible as the printed word would be: and what is more, variations of temperature, pressure, and other physical conditions affect the spectrum in such a way as to announce themselves—as if the type with which the name of the material is printed were altered in size and style to indicate its physical conditions. You see how full of information such a spectrum is—and it makes no difference how far the light may have traveled before it reaches the eye: if it is only bright enough to be seen, the distance does not in the least affect its legibility.

And now for a fact still more curious. If through a mass of glowing gas giving such a spectrum as I have just described, a stronger light is made to pass, then upon the spectrum of this stronger light the spectrum of the gas will be seen *reversed* (that is, all its bright lines will become dark—those that were brightest before will be the darkest now), and we shall have a bright spectrum with dark lines in it, as significant as one of bright lines alone.

As long ago as 1806 Wollaston found that the spectrum of sunlight was crossed by numerous dark lines.

In 1826 Fraunhofer again and independently discovered the same thing, aud made a map of the spectrum, giving designations to many of the principal lines —to eight especially, which are to this day known as the

Fraunhofer lines A, B, C, D, E, F, G, and H; the first of which is at the extreme red end of the spectrum, D in the yellow, F in the blue, and H in the extreme violet.

Although in the meanwhile important facts were ascertained by many observers, some of whom came very near the final great discovery, it was not until about 1858 when Kirchoff and Bunsen took up the subject, that the value and significance of the spectrum came to be fully understood.

They first ascertained, or at least distinctly announced the principles I stated a few moments ago; gave to the spectroscope essentially its present form; investigated and mapped the spectra of many substances; and discovered three new metals, to which a fourth was soon added by Crookes.

Kirchoff made a minute and accurate map of the solar spectrum containing more than 2,000 lines, and comparing it carefully with the bright-line spectra of different metallic vapors and gases, he demonstrated from a distance of nearly a hundred millions of miles, the presence of many substances at the surface of the sun, by showing that dark lines in the solar spectrum coincided accurately with the bright lines given by their vapors. The following table exhibits the names of the elements known to exist in the sun, and the number of lines in their spectra ascertained to coincide with the solar lines. As to the majority of the dark lines in the solar spectrum, however, their origin is still unknown, and remains a tempting subject of research.

TABLE.

Substance.	No. of coincident lines.	Substance.	No. of coincident lines.
Hydrogen	4, all conspicuous.	Chromium	18, none very conspi.
Sodium	9, 2 are conspicuous.	Cobalt	19, none very conspi.

Substance.	No. of coincident lines.	Substance.	No. of coincident lines.
Barium	11, none very conspi.	Nickel	33, none very conspi.
Calcium	75, many conspicuous.	Zinc	2, none very conspi.
Magnesium	4 (+3 ?), 3 v'y conspi.	Copper	7, none very conspi.
Iron	460, many conspicuous.	Titanium	200, none very conspi.
Manganese	57, none conspicuous.		

There are only doubtful coincidences in the case of gold and aluminium; and absolute discordance in the case of silver, mercury, antimony, arsenic, tin, lead, cadmium, strontium and lithium. Nor do we find any signs of silicon, carbon, oxygen, or nitrogen, each so abundant on the earth. It is to be remembered, however, that this mere negative evidence goes but little way towards proving their absence from the sun.

From what has been said it is easy to see that the natural explanation of these dark Fraunhofer lines is this —they are produced by the filtering, so to speak, of the light from the photosphere through an atmosphere in which the different substances exist in the gaseous form. Kirchoff supposed (as Zöllner now does) the photosphere to be a liquid surface, and that it was overlaid by an extensive atmosphere of vaporized metals.

But great doubt was soon thrown upon this theory by several circumstances. If true, it was argued that the dark lines ought to be more conspicuous in the light which comes from near the edge of the solar disc than in that from the central portions.

The difference, if any, is very slight. (But I feel quite sure there is such a difference.)

So also at the time of an annular eclipse the dark lines ought to appear stronger than under ordinary circumstances. At least Janssen argued so; (I think wrongly, in ignorance of a fact which would partly compensate for the hiding of the sun's centre) and yet at

the annular eclipse of 1867 he found no such effect with the most careful observation.

Then also at a total eclipse, when the sun is entirely covered, the spectrum of this atmosphere ought to be seen as a spectrum of thousands of bright lines—corresponding to the ordinary dark lines; or, as we say technically, the ordinary solar spectrum should be *reversed.* But nothing of the kind was seen at the eclipses of 1868 or 1869.

Accordingly, since the darkening of the sun's edge could be fully accounted for by the chromosphere which was discovered in 1868, and of which more anon astronomers generally came to think that Kirchoff was mistaken, and that the Fraunhofer lines were produced, not by a stratum between us and the photosphere, but in the photosphere itself—that is, by the vapor in which the little globules of condensed liquid float, just as in our own terrestrial clouds each minute drop of the water-dust is surrounded by an atmosphere saturated with water-vapor.

And yet so far as the atmosphere is concerned, Kirchoff is right after all, except as to its extent; it must be very shallow—not over 1,000 miles thick at most.

The only reason why the dark lines of the solar spectrum were not seen reversed into bright ones at the eclipses of 1868 and 1869 is that the phenomenon is so sudden and evanescent as to be rather difficult of observation. It *was* observed in 1870 in Spain, and a most beautiful spectacle it was: as the moon moved over the last portions of the sun's disc, the spectrum became somewhat fainter, and the dark lines gradually disappeared, until all at once, just as the last ray of sunlight was stopped out, hundreds of bright lines flashed into

view as suddenly as the stars from a bursting rocket-head, and then gradually, but rapidly, faded away, until within a second and a half, or two seconds at most, they had vanished. This observation, which was for a while rather doubted in some quarters, was fully confirmed by several observers at the eclipse of last December.

Capt. Maclear, for instance, writes, "as totality came on, the light decreased, and the lines increased exceedingly rapidly, in number and brightness, until it seemed as if every line in the solar spectrum was reversed: then they vanished, not instantly, but so rapidly, that I could not make out the order of their going."

I think therefore we are warranted in believing that above the photosphere, the lower strata of the solar atmosphere for a height of from 500 to 1,000 miles contain pretty much all the substances whose presence is indicated by the dark lines in the solar spectrum, and that in the absorption of these lower strata the lines mainly originate. At a greater elevation the solar atmosphere, except in cases of unusual disturbance, becomes much more simple in its composition, consisting principally of hydrogen with two or three other substances whose nature is as yet unknown.

CHROMOSPHERE AND PROMINENCES.

At the total eclipse of 1842 many of the observers noticed strange rose colored objects hanging upon the outline of the moon. Some called them "red flames," others preferred the non-committal name of "prominences" or "protuberances"; and at once a brisk discussion arose as to their nature and location. Some thought they were in our own atmosphere, others that they belonged to the moon, but most, and rightly as it

has turned out, that they were solar. They have been observed at every subsequent eclipse. In 1860 it was finally and completely settled that they are solar clouds of some kind. Photographs of the eclipse as seen in Northern Spain were taken by Secchi and De la Rue, and they distinctly showed that in the progress of the eclipse the moon moved over these objects covering those on one side, and uncovering those on the other.

It was not, however, until 1868 that their true nature was made known, and then by the spectroscope.

In August of this year occurred in India and Burmah a great eclipse, of which the totality endured more than five minutes. It was observed with great care, all along its course, and the spectroscope for the first time was brought to bear upon such a phenomenon, with results most brilliant and satisfactory—a glance accomplished what by any other method yet known would have required years of patient labor. The prominences showed a spectrum of bright lines—they are therefore gaseous; the lines were several of them coincident with those of hydrogen, and therefore hydrogen is one of their principal constituents. But I ought, in fairness, to say that the last result could hardly have been gathered from the eclipse observations alone, since the different observers Tennant, Herschel, Pogson, Rayet and Janssen, were not quite in accord as to the positions of the bright lines seen by them.

The lines were so brilliant that Janssen, who was favored with an atmosphere of unusual transparency, at once exclaimed "I will see those lines again!" He was prevented by clouds from making the attempt on the afternoon of the eclipse, but the next morning the sun

rose unobscured, and as soon as he could direct his instrument to the point on the edge of the solar disc where the day before he had seen a great prominence, there sure enough *were* the lines again, unmistakable, bright and clear; three of them,—one in the red and one in the blue, coinciding exactly with the two most conspicuous dark lines known to be due to hydrogen, and a third in the yellow near the sodium line, but not agreeing with it nor with any dark line in the solar spectrum: it is still a mystery to what substance it owes its origin.

The only reason why we cannot see these prominences under ordinary circumstances is simply this: the air in the neighborhood of the sun is so intensely illuminated as completely to mask them: if we could only devise some means to weaken this air-light without much affecting their own luminosity, we could see them well enough at any time. Nearly two years before Jánssen's observation it had occurred to several English physicists independently of each other, that if the prominences were gaseous the spectroscope would accomplish the desired object, because the air-light, being simply reflected sunlight, would be dispersed into a long and comparatively faint spectrum by passing through the prisms, while on the other hand the prominence-light being less complex, and containing only a few kinds of rays would not be much affected: indeed the more powerful the spectroscope, the more easily should the bright lines of the prominence spectrum be seen, since every increase of dispersive power would darken the background without sensibly diminishing their own brightness.

Huggins and Lockyer both tried the experiment, but without success; partly because their instruments were

hardly of sufficient power, but more because they did not know in what part of the spectrum to look. After the discovery was once made Mr. Huggins saw the lines easily enough with the same instrument which had failed before.

Mr. Lockyer did not drop the matter however, but with the help of the Royal Society set about procuring a new and more powerful instrument, which after many vexatious delays he at last received in Oct., 1868, after Janssen's observations were made, but before the news had reached England. He at once applied it to the sun, and his success was immediate and complete. He saw the three lines, and found that they are visible everywhere around the sun, and that the prominences are mere extensions or off-shoots of this stratum of hydrogen to which he, or to be more exact, his associate Dr. Frankland, soon after gave the name of chromosphere*—*i.e. color-sphere*,—alluding to the vivid redness of this layer and of the prominences which are seen during an eclipse.

He immediately communicated his discovery to the Royal Society and to the French Academy, and by one of those singular coincidences that sometimes occur, his letter and Janssen's arrived in Paris together, and were read at the same meeting of the Academy, where they created the greatest enthusiasm and excitement.

* Proctor objects to this name on etymological grounds, and would have us revert to the term "Sierra," first used by Airy in describing the appearance of the "rugged line of rosy projections" which appeared just before the close of totality at the eclipse of 1851; or if we must retain the word, he would at least change it to "chromato sphere."

The term, however, has been so generally adopted that it will probably stand as it is, notwithstanding the slight inaccuracy of its formation.

Huggins soon after discovered that by simply widening the slit of the spectroscope it is possible not only to perceive the bright lines belonging to the spectrum of the prominences, but to see the prominences themselves in all their beauty of form and detail—and they *are* beautiful in the extreme—like the bright clouds in a sunset sky seen through a half opened door from a little distance.

But before proceeding further, let me in a few words introduce you to the instrument we use in making such observations—the spectroscope.

Essentially it consists of three parts. A collimator, as it is called, a small telescope, and between them a prism or train of prisms.

The collimator itself is very like a telescope in appearance, consisting of a tube, in one end of which is a convex lens, and at the other end, just in the focus of the lens, is placed the slit, usually about $\frac{1}{8}$ of an inch long, and from $\frac{1}{10000}$ of an inch to $\frac{1}{20}$ of an inch wide according to circumstances,—its width being adjusted at pleasure by a screw. The collimator of a spectroscope for astronomical purposes is seldom more than an inch or so in diameter, and from 5 to 10 inches long; the telescope of the instrument is usually of about the same size, magnifying from 5 to 20 times. The train of prisms, consisting of from two to six, is so placed that the light from the slit, after going through the lens of the collimator must pass through them before reaching the telescope. Sometimes by a reflection at the end of the train the light is made to pass twice through the prisms, thus doubling the dispersive power and permitting the whole to be arranged in a very compact and convenient form. This is the case with the

instrument belonging to the observatory of Dartmouth College, which is represented in figure 2. It is attached to the eye end of a large equatoreal telescope, which is mounted upon an iron pillar, and provided with clock work to enable it to follow accurately the motion of the sun. The object glass of the equatoreal forms upon the blackened plate in which is set the slit of the spectroscope, a bright distinct image of the sun, just such as any one may see upon the ground glass of a photographer's camera when adjusted for taking a picture.

Directing the telescope so that this image shall fall fairly upon the slit, and looking into the eyepiece of the spectroscope, one sees a portion of the spectrum, stretching across the field of view like a piece of beautifully colored ribbon, about an inch and a half wide by 8 or 10 inches long, barred with a countless number of dark lines of varying intensity and width.

By means of a proper tangent screw we bring to the centre of the field the dark line C, which is situated in the midst of the vivid scarlet, and carefully adjust the focus. Now gently moving the telescope until the slit becomes exactly tangential to the image of the sun, just at the moment when the slit passes off the edge of the image and the remainder of the spectrum suddenly grows faint, this C line, before so impressively black and hard, at once flashes out with a magnificent scarlet splendor.

Now open the slit a little and you see the ragged edge of the chromosphere, with perhaps here and there a prominence; a little wider, and you see more and more of the prominences, though not quite so distinctly because the background is not so dark. What was

before the black C line now seems merely like a darkish stripe across the spectrum, and in it, or through it rather, appear the beautiful cloud forms.

With this instrument, when the state of the air is good, we can observe the chromosphere and prominences with nearly the same ease and precision as the spots themselves with an ordinary telescope, and the beauty of their forms and the rapidity of their changes make them objects of unrivalled interest.

Indeed it is not only possible to *see* them with the spectroscope, but by attaching a small camera to the eyepiece, photographs even have been taken—not thus far however with sufficient success to amount to anything more than a demonstration that the thing is feasible.

The chromosphere is from six to ten thousand miles in thickness on the average, but varies greatly, especially in the neighborhood of spots. Over the centre of the spot there is often a well marked depression, but at a little distance the surface is elevated and violently disturbed. Every where indeed, its upper surface is ragged and uneven in the extreme, so much so as to suggest the idea, which is maintained by Proctor, that it is not a *stratum* at all, but made up of many separate jets of heated hydrogen issuing through orifices in the photosphere at considerable distances from each other, and appearing to form a continuous envelope only as an effect of perspective. For myself I have never seen anything inconsistent with this theory, but Secchi describes certain observations in which he has occasionally found the upper surface of the chromosphere flat and smooth, and on the whole it seems rather more likely that it is really continuous, but in a state of great and almost perpetual agitation. One observer describes its appear-

ance as resembling a field in which numerous piles of brush are burning; another a prairie on fire. It is usually much brighter at its base, though this may be merely an optical effect, since near the limb of the sun we are looking through a great depth of the transparent gas.

In its spectrum the lines of hydrogen, four in number, are specially conspicuous; a very bright line near D*, with two others, one exceedingly faint and difficult of observation in the extreme red end of the spectrum between B and a, and another more easily seen about one third of the way from G to F, also appear to be constantly present, and to belong to some substance hitherto unknown, which is intimately associated with hydrogen at the sun. Besides these seven, the lines of sodium, magnesium and barium are often seen in portions of the chromosphere where anything unusual is going on, and not unfrequently many of the lines of iron, titanium, chromium and other elements appear. On one occasion indeed Mr. Lockyer reports seeing *hundreds of bright lines*, and I myself have made a list of more than one hundred, all of which I have observed repeatedly. Indeed zinc and copper are the only substances known to exist as vapor in the solar atmosphere, which have not been detected in the chromosphere; and there can be little doubt that under favorable circumstances, *i.e.* at the top of a mountain, or perhaps in the clear sky of Italy or Asia Minor one would find *all* the lines of the spectrum reversed in the base of the chromosphere, just as at a total eclipse, by means of an instrument of sufficient dispersive power.

* Frankland has proposed the name "Helium" for the unknown substance to which this D_3, as it is called, is due.

I hope before long to be able to try the experiment at the summit of our Pacific Railroad, at an elevation of nearly 8,000 ft. In Italy Secchi often sees the spectrum *continuous* at the base of the chromosphere, *i.e.* the dark lines of the ordinary air-spectrum have disappeared—the preliminary of course to a distinct reversal.

But the chief interest of spectroscopic observation on ordinary occasions centres in the prominences.

These vary greatly in appearance and magnitude, as much as our terrestrial clouds, but may be roughly divided into two classes, the eruption prominences and the cloud-formed. The latter are not very brilliant but are comparatively permanent, and frequently of great size, from 20,000 to 80,000 miles in height, and of even greater length: generally they are connected with the chromosphere below by something like a stem, but not unfrequently they float entirely separate. In structure they sometimes resemble a stratus cloud, but more generally are cirriform, made up of little wisps and filaments, whose delicate beauty defies description and delineation. So far as my own observation goes they are the debris of the eruptive prominences; I have never seen a detached cloud that did not seem to have been formed by breaking off from a prominence attached to the chromosphere, or to have been thrown up from the chromosphere. But Secchi asserts that he has seen such isolated clouds form and grow in free space, just as our own clouds do; as yet I have never been able to verify the statement, and the phenomenon, if it really occurs, is not an easy one to explain.

The eruptive prominences are very different, and far more active: they are often mere streams of intensely brilliant light which rise straight and sharp, but commonly

inclined from the vertical. Not unfrequently they attain a height of 15,000 or 20,000 miles in a few minutes, and then sink down to be followed by others, or the streamer detaches itself and flies upward; sometimes they very exactly simulate jets of water rising and falling back in graceful curves.

This kind of prominences is especially common in the neighborhood of a large spot, and when such an object is just passing off the limb the spectroscopic appearance of the neighborhood is very interesting. Examining the spectrum of the spot itself (the slit of the instrument being made very narrow) we shall probably find it to be much the same as that of the rest of the sun except that it is not so brilliant and that many of the lines are much widened and thickened in it. But the hydrogen lines instead of being dark are very commonly reversed, and when this is the case, on opening the slit we shall see as a bright patch, what in a telescope would be the dark umbra of the spot, while all along the limb spikes and streamers of chromospheric matter evince the greatest activity.

Fig. 3 represents a spot and its accompanying prominences which was thus observed Oct. 5, 1871, and in the symmetry and beauty of the jets exceeds anything else I have ever seen. The extreme elevation of the jets a little exceeded 30,000 miles. One very curious feature was the little horn which appeared to grow out of the spot itself. This is very rare, since the prominences appear as a general rule to accompany the faculæ rather than the spots.

Besides the streamers and jets we have many other forms of the eruptive prominences.

Often we find them resembling in shape gigantic

mushrooms, sometimes great pyramids, sometimes the smoke of a distant steamer; but it is to be noticed that in almost every case where we can see their connection with the chromosphere, it is by a stem exceedingly fine and narrow at the base. Occasionally the stems appear to be of considerable size, but then it is almost invariably found that they are made up of a multitude of fine streams intertwined in the most intricate manner. In prominences of this sort we often find other substances than hydrogen: in the ascending jets and in the clouds that terminate the jets sodium and magnesium are especially common, and barium is sometimes met with. The other substances whose spectrum is sometimes reversed in the chromosphere seldom seem to reach an elevation greater than a few thousand miles, probably because they cease to be luminous at a lower temperature than the others.

The whole appearance of this class of prominences indicates almost irresistibly that they are formed by the ejection of gaseous matter through orifices in the photosphere, and it is from this point of view that the hypothesis of Zöllner (who, you remember, holds that the centre of the sun, if not itself liquid, is covered by a liquid shell) assumes the greatest plausibility. For if these prominences really are thus formed by the forcing out of gas under pressure the cloud theory of the photosphere appears totally inadequate. As Zöllner shows, the difference of pressure between the inside and the outside of the orifice through which the gas is driven must be simply enormous, to account for the observed velocities which *often* exceed 100 miles per second, and sometimes are more than double, carrying up the hydrogen to elevations of one hundred, and one hundred and

fifty thousand miles, and on one occasion even as high as two hundred thousand miles.

The eruption last referred to, which in some respects exceeded anything else yet on record, occurred on the 7th of Sept., 1871, and is illustrated in Figs. 4 and 5. Fig. 4 represents a large prominence then upon the western limb of the sun, as it appeared at half-past 12: it had changed but little since the preceding day, and was remarkable for nothing except its magnitude, which was somewhat greater than ordinary. It was about 100,000 miles long by 55,000 miles high. Fig. 5 represents its appearance half an hour later: it had literally blown up in the interval, and while I was watching I saw some of the filaments ascend from an elevation of 100,000 miles to one of 200,000 in ten minutes of time, with an *average* velocity of 167 miles per second. Proctor has conclusively shown two things—viz., that *if* the filaments I saw rise, actually started from the level of the chromosphere they must have had an initial velocity of more than 250 miles per second, and further, must have experienced considerable resistance between the heights of 100,000 and 200,000 miles. Indeed, as he shows, it is much more likely, considering the probable amount of resistance encountered in passing through the chromosphere and atmosphere up to the level of 100,000 miles, that the initial velocity must have exceeded 500 miles per second. The maximum velocity of a cannon ball is twelve hundred times less. No explosive now known to human chemistry could hurl a missile with a velocity in any way even remotely comparable.

It would follow further, that if any denser material was ejected from the bowels of the sun by this explo-

sion, as I think it may fairly be called, it would never return to the sun again. It would fly off into space and might possibly descend upon the earth as a meteor: in this view, as Proctor suggests, it is by no means impossible that some of the specimens of meteoric iron in our cabinets are really pieces of the sun.

But these results and speculations are so startling that although on the whole conceding that the view upon which they are based is more probable than any other, yet I often feel disposed to take refuge in another hypothesis as to these solar eruptions—that they are only apparent, not real; that we have to do in these seemingly violent motions with a transfer of luminosity and not of matter: that what occurs when a filament of hydrogen appears to rise with such a velocity, is the rushing of a flash, or the transmission of a luminous pulse along a train of hydrogen already in place—the phenomenon being something such as we see in the pulsations of the aurora borealis, or to take a humbler illustration, in the play of the flames over a newly replenished grate of bituminous coal.

Still the evidences of actual motion are so numerous and conclusive, that on the whole I imagine the hypothesis is not tenable, and that we must content ourselves with hoping that the sun will not take to bombarding us in some fit of passion.

What are the causes of such eruptions it is impossible to state as yet with any certainty; still, knowing what we do of the enormous amount of energy which the sun is continually pouring out in the form of heat, it is nothing strange that such things should occur, and that on a solar scale.

The careful investigations of Secchi have shown that

while the prominences, unlike the spots, are found on all parts of the solar disc, they are more common in some portions than in others, being most abundant precisely in the same latitude as the spots, that is, about 15° or 20° from the equator on each side; they are most infrequent, however, neither at the poles nor equator, but at a distance of about 30° from the poles.

The number visible at any one time is very variable. During the past three years I have never gone around the whole circumference of the sun with the spectroscope without finding two or three of reasonable size, and on one occasion I found twenty-six; perhaps from ten to twelve would be a fair average. But it must be remembered that during the past year or two the solar activity, as evidenced by the number of spots, has been at a maximum: how it will be with the prominences during the next four or five years, it is hardly safe to predict, but they will probably sympathise to some extent.

The forms and motions of many of the prominences are such as to show that they float in an atmosphere of different material and lower density, in which there are winds of great violence, and sometimes whirling storms like those in our own atmosphere. Not unfrequently the top of a prominence, which appears to be quiet at its base, is torn to pieces by contending currents which snatch off shreds and carry them away with enormous velocity.

From a careful study of the direction, inclination and motion of the filaments which compose these clouds Secchi concludes that in this solar atmosphere immediately above the chromosphere there is a well marked constant current blowing from the equator towards the pole—and with this my own observations agree.

As to the nature of this upper atmosphere, we as yet know comparatively little, for it is only directly visible at the time of a solar eclipse.

Indeed for several years its very existence was stoutly denied. Mr. Lockyer, from observations upon the behavior and appearance of one of the hydrogen lines (F) was able to show that in a prominence even at its base the gaseous pressure is very small, not more than a 50th part of the pressure of our atmosphere, and that it diminishes very rapidly as the elevation increases: hence he concluded, and for a time it was generally admitted, that there could be no atmosphere of any extent above the level of the chromosphere, for such an atmosphere of any known gas resting in equilibrium upon the surface of the sun must in consequence of the intensity of the solar gravity exert an enormous pressure. The only possible escape from this conclusion apparently lies in admitting either that the gas of which this atmosphere is composed is no known gas, but a new substance of inconceivably greater tenuity than hydrogen itself, or else that it is acted upon by some solar repulsion in such a way as to virtually annihilate its weight.

But the atmosphere is there beyond a doubt, and extends to at least 200,000 miles above the photosphere.

And this brings me to the last topic of the lecture,—

THE CORONA,

The crown and halo of glory, which during an eclipse encircles the sun.

From immemorial antiquity this magnificent spectacle has been well known and enthusiastically described; and it is beautiful and impressive exceedingly, almost

beyond the conception of those who have not seen it for themselves.

If on such an occasion the sky is clear, the moon appears of almost inky blackness, excepting a little diffuse light around the limb—just enough to bring out her rotundity in the most striking manner; and close around her outline lies a ring of pearly greenish light of almost dazzling brilliance at its inner edge, where it contrasts with the still more brilliant prominences, which blaze like burning rubies; it gradually fades out towards its outer limit at a distance of from ¼ to ½ the moon's diameter, and is terminated by an irregular and very indefinite boundary, which is usually roughly quadrangular, with its diagonals crossing the sun's equator at an angle of about 45°. It is always distinctly radiant in its structure, made up of filaments which stand nearly perpendicular to the surface of the sun, and yet in many places are strangely curved and intertwined.

For the sake of distinction this may be called the "inner-corona"—but it is by no means the whole phenomenon.

Often, perhaps always, long beams and rays of delicately colored light are seen extending to a much greater distance—not unfrequently twice the moon's diameter—and certain dark rifts or gaps reach outward from the very body of the moon to an equal distance through the faint, but pretty extensive luminosity which surrounds her.

Photography has secured a most beautiful record of the inner corona in the remarkable picture obtained by Professor Winlock's party of the eclipse of 1869: in this respect neither of the pictures of the eclipse of 1870 can compare with it, but the photograph of Mr. Brothers

in Sicily, shows more of the diffuse light, and gives some idea of the appearance of the rifts. Whether the photographs obtained in India last December are superior, we have yet to learn, but as the weather was favorable we have everything to hope.

As to the cause of these phenomena there has been great discussion, and even yet the problem is only solved in part. Some have held that the corona is merely the sunlight streaming out from behind the moon, others that it is formed by a lunar atmosphere; some that it is formed in our own air, and some that it is at the sun—a phenomenon of the solar atmosphere; and finally most astronomers believe, I might say *know*, as *things* now stand, that it is a composite phenomenon, of which a part is certainly solar, a part terrestrial, and a part of origin as yet uncertain.

That the inner corona is a solar envelope was first demonstrated at the eclipse of 1869, and by the spectroscope. In 1868 attention was concentrated upon the prominences, and although the bright line of the corona spectrum appears to have been really seen by Pogson and Rayet it was not recognized as coronal, and the result announced was not such as to lead to any definite conclusion.

In 1869 especial attention was paid to the corona, and two of the American observers found that its spectrum was characterized by a brilliant green line: this line*, the now somewhat famous 1474, is precisely coincident with a distinct, but inconspicuous dark line in

* As there has been some misconception and mis-statement in regard to this matter, perhaps I may be permitted to put it right.

Only two observers saw and recognized this line as belonging to the

the solar spectrum marked by Kirchoff and also by Angstrom as due to iron. One of the observers saw also two other faint lines which he thought might be, and probably were, coronal—an observation since only partially confirmed.

But considered as a demonstration of self-luminosity one line is as conclusive as a thousand, and it is easy to see that any self-luminous corona must be solar.

Accordingly those who denied the possibility of any extensive atmosphere above the chromosphere, received the observation with great suspicion; but in 1870, and

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spectrum of the corona, Professor Harkness and myself. Professor Pickering saw it, but his instrument, what would now be called an *integrating* spectroscope and unconnected with any telescope, gave no means of determining whether any particular line in the spectrum was due to the prominences or to the corona: the fact that he saw it however, and that in that form of instrument it was the brightest of all the lines seen, was of the highest importance in proving it to be truly coronal.

Professor Van Vleck also saw the line, but recognized no difference between it and the other lines as to origin.

So far as I can learn neither Professor Winlock nor Dr. Peters recognized its character, if they saw it at all. I know of no other spectroscopic observations of that eclipse.

As to its position, Prof. Harkness with his one-prism instrument determined its place, at 1497 of Kirchoff's scale—a very creditable approximation for such an instrument.

My own instrument had five prisms, and on account of the large size of its collimator and telescope possessed probably full eight times the dispersive power of the other. I had discovered the 1474 line to be occasionally bright in the chrosmosphere spectrum nearly a month previously (Mr. Lockyer saw it before me however), and naturally enough was observing it a few minutes before the totality, when it was already plainly reversed; so that I needed no measurements to give me its position on finding it in the corona spectrum.

again last December, the observation was fully verified, and so far as the inner corona is concerned the question may be considered as settled. Indeed the observations of last December have shown conclusively, that hydrogen is also an essential constituent of this *coronal atmosphere*, as Janssen proposes to call it—hydrogen at a lower temperature and density of course than in the chromosphere. This fact was most beautifully brought out by a new mode of observation employed for the first time at the last eclipse by Lockyer and Respighi. It consists simply in looking at the eclipsed sun through a prism, either with or without a telescope—better *with* however, as was the case with Respighi. What he saw was this: Three exquisite rings, one in the red corresponding to the C line, one in the green corresponding to 1474, and one in the blue, corresponding to F. Of these the green ring was the brightest, the largest and the best defined, attaining about 7′ of elevation; the red ring was nearly as bright and large, but the blue was smaller and fainter.

The observations of Janssen agree with these in indicating the presence of hydrogen, and he was so fortunate as to catch glimpses of some of the dark lines of the solar spectrum in the coronal light, an observation which goes far to show that in the upper atmosphere of the sun there are also solid or liquid particles which reflect the sunlight from below, like smoke or cloud.

But while it is thus settled that the inner corona is really solar, many problems with reference to it remain unsolved.

The first relates to the nature of the substance which produces the 1474 line. In respect to this there is a good deal of difference of opinion. Since the line

coincides with a line in the spectrum of iron, many, perhaps most, astronomers consider it due to that metal: but in this case we must suppose either that iron-vapor is less dense than hydrogen gas, or that it is subject to some peculiar solar repulsion which maintains it at its elevation, or else that some kind of atmosphere as light as hydrogen, is full of iron dust, between the particles of which pass electric discharges that develope this line.

Still considering that this line is one of the least conspicuous in the spectrum of iron, that it is the shortest of the iron lines, and that none of the many hundred others are found associated with it in this corona spectrum, it seems more natural to assume at once that it is due to some new kind of matter, in which view Mr. Lockyer and many other high authorities concur.

Another problem, and perhaps the most perplexing of all, is the reconciliation of the strangely discordant observations upon the polarization of the coronal light: observers of equal skill, sometimes even the same observer at different times or with different instruments, obtain results whose flat contradictoriness, as interpreted by our present optical knowledge, is almost comical; Thus at the last eclipse, while Mr. Lockyer and Dr. Thompson found only a vertical polarization covering everything, Captain Tupman and Mr. Lewis found it as strongly radial. Undoubtedly the key to these discrepancies will in time be found either in the peculiar atmospheric conditions of the observers' stations, or in the instruments employed, but until they are explained very little use can safely be made of the results.

Our knowledge as to the nature and constitution of the outer corona, the assemblage of dark rifts and

bright rays which overlies and surrounds the inner corona, is still less complete. It is not even certain that it is solar at all, though I think astronomers generally consider it so, in the main at least. A few authorities of high repute I suppose still believe it to be caused by some action of our atmosphere, and others suppose it due to cosmical dust between us and the moon.

Although at the time of the middle of the eclipse the observer is so deeply immersed in the lunar shadow that no illumination of the air by real sunshine can possibly affect the sky in the moon's neighborhood, yet of course the bright light of the inner corona (which several times exceeds that of the full moon), as well as that from the prominences, must cause a certain amount of "atmospheric glare;" and although it is difficult to see how this is to account for the rays and rifts, it might be rash to deny that it may do so in some manner yet to be discovered. It is quite certain that some of the phenomena observed just at the beginning and end of totality are really caused by it.

So also a light haze of meteoric dust between us and the moon would give results much resembling those observed. The inequalities of the moon's limb would cause the outer surface of the moon's conical shadow to be not smooth, but channeled or furrowed, and that most distinctly near the moon itself. Still when we come to details the theory seems to break down, and I do not think is now considered tenable.

If the rays and rifts are really atmospheric or even cislunar, it would hardly be possible that they should present the same appearance at different stations along the line of totality: indeed they would probably change

their appearance every moment, even at the same station, and some observers contend that this is really the case, though the general impression is the other way.

But it is almost universally admitted that proof of the invariability of these markings, and especially of their identity as seen at widely separated stations, would amount to a demonstration of their solar nature. It is found, however, that eye-sketches cannot safely be depended upon. The time is so short that accurate measurements are impossible, and the excitement of the occasion is so great that even the most faithful artist projects his own personality into his picture to a surprising degree. The drawings made by persons standing side by side differ to an extent that is sometimes really ludicrous, and has induced more than one astronomer who had not himself seen an eclipse, but judged only from the written accounts and sketches, to declare his belief that this whole outer corona is a merely subjective phenomenon, simply the result of the observer's imagination, or to put it in Saxon, "all in his eye."

Hence the importance attached to photographs. These undoubtedly fail as yet to catch many of the faint markings and delicate details visible to the human eye, but their testimony, as far as it goes, is unimpeachable.

Up to 1869 no photograph of the corona had ever been obtained. I have already referred to the beautiful picture of that year's eclipse, taken by Mr. Whipple, under Prof. Winlock's direction, but even this shows almost nothing of the outer corona, and there were no other pictures to compare with it. The interest was then mainly centred in the prominences and most of

the photographic apparatus was arranged accordingly.

In 1870 in Spain, Lord Lindsay's party at Santa Maria, and Prof. Winlock's party close by, at Jerez, and in Sicily, Mr. Brothers at Syracuse, all obtained pictures, which though somewhat defective on account of the unsatisfactory condition of the weather, still show something of the outer corona; one deep rift especially, which seemed to cut down through both the outer and the inner corona clear to the limb of the moon, and was to the naked eye one of the most conspicuous features of the eclipse, appears unmistakably the same in all, marked by two small prominences on the edge of the sun just at its point. Many other points of detail also come out identical in the Spanish and Sicilian pictures —with, it must be admitted, differences also.

Altogether, though the evidence of these pictures bears very strongly in favor of the solar origin of the outer corona, it is probably best to wait for the testimony of the photographs of the recent eclipse in India before coming to a final conclusion. These pictures,* more than twenty in number, taken most of them under the finest atmospheric conditions, and with all the ad-

* In an article which has just appeared in the April number of the Popular Science Review, Mr. Proctor says:

"None of the photographs show so great an extension of the corona as is seen in Mr. Brothers's photograph, taken at Syracuse in December, 1871; but, on the other hand, the coronal features are better defined; and necessarily the great number of the photographs renders the value of the series singularly great. The agreement between the views, as well those taken at different times during totality as those taken at different stations, is greater even than the solar theory of the corona absolutely requires, for it is not incompatible with recognizable variations. However, not even such difficulties, or at least none worth noticing, present themselves. We have in

vantage of previous experience, can hardly fail to utter some authoritative decision.

And if it be solar, then arise a number of most interesting and difficult problems relating to its cause and nature, for while regarded as a mere glare in our own atmosphere it would be a phenomenon of little dignity or consequence, the case is far different if we find it to be made up of columns of luminous matter whose length is reckoned by millions of miles, and of corresponding diameter, resting upon the sun, or projected by him into space.

Were the columns of the same material as that which composes mainly the inner corona (the 1474-stuff, as we may call it provisionally), then it is probable that Respighi, on looking through his prism-armed telescope, instead of seeing the green image as a simple ring, just like those in the red and blue which were due to hydrogen, would have fouud it a complete corona, rays, rifts and all. Such a result would have been conclusive, and I more than half expected it. The negative result however is indecisive, since he might have failed to see the rays either on account of their faintness, or for want of enough dispersive power to weaken sufficiently the light of the continuous spectrum that formed the background to the images; similar remarks apply to Mr. Lockyer's observation. Indeed that something was unsatisfactory with his apparatus seems evident from the fact that the images which Respighi found to extend to

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all the views the same extensive corona, with persistent rifts similarly situated."

This is the only statement I have yet seen with reference to the result of the comparison of the photographs.

April 16, 1872.

a distance of 7′ from the edge of the moon, were estimated by him as only 2′ wide.

Taking the observation as it stands however, there is a probability that the streamers shine mainly by reflected sunlight, and are composed of *haze, i.e.* minute particles of solid or liquid matter scattered through a gaseous medium.

And assuming them to be at the sun, there appear to be two possible lines of explanation. We may look at them as due to simple mechanical actions—formed by matter blown out of the sun by the same forces that eject the matter of the prominences; and so enormous are these forces that in the light of what I have seen for myself of the sun's eruptive energy, the explanation seems to me far more probable than it did a few months ago. Still it is difficult to see how the enormous solar gravity should fail to bend and curve these rays, and bring them back towards its surface.

The other explanation would regard them as made up of particles, not necessarily moving with any great velocity, arranged in columns and rendered luminous by solar forces analogous to those terrestrial forces which produce our own aurora. It is true we know but little as to the manner in which the auroral beams are formed and made luminous, only that in their origin they are what we call magnetic and electrical to a great extent.

But this does not bar the analogy. On the contrary, the connection between the disturbances of the solar surface and the terrestrial magnetism is so intimate, and it is so improbable that the intense thermal and luminous activity of the sun should not be accompanied by a corresponding development of electric energy, that it would seem altogether likely that the

magnetic and electric phenomena of the earth must have their solar analogues, and that upon the solar scale. One curious fact bears in favor of this view. One of the fainter lines in the spectrum of the aurora appears to coincide with 1474: as if in our own auroral beams we had the same substance which forms the staple of the sun's corona.

Still this auroral line is so rarely seen (it must not be confounded with the *principal* line of the aurora-spectrum), so faint and difficult of observation, that its position can hardly be considered as accurately known, and the apparent coincidence may be merely accidental.

Could the corona by some means be brought within the range of daily observation, as the chromosphere has been, we might hope soon to come to a more perfect knowledge of its nature. Its light is so feeble that it is difficult to conceive the possibility of this, and yet who can say what science may not accomplish? In the mean time astronomers wait with what patience they best may be for the eclipse of 1878.

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